Digital Technologies in Teaching Physics: An Analysis of Existing Practices

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***Abstract* - The article raises the problem of using digital technologies (DT) in teaching physics. To identify scientific and methodological results on the use of DT in teaching physics, an analysis of publications contained in the Scopus / Web of Science databases and scientific and methodological publications of Ukraine is presented. The following directions have been recorded: the use of various digital tools as tools for the study of physical processes; the use of applications to solve physical problems, the use of virtual and digital physical laboratories, the use of virtual and augmented reality to teach physics, and the use of specialized environments to model physical processes. Separately, virtual physical laboratories are noted – computer environments that allow you to simulate the behavior of real-world objects in conditions that are close to real ones. The PhET resource, which contains online laboratories to support the study of various topics of the physics course, is briefly described. Based on the results of the survey of teachers, Ukraine's practices of using digital technologies in teaching physics are summarized. In particular, there revealed a certain teacher bias regarding using virtual physical laboratories to teach physics.**

Keywords - teaching physics; digital technologies in teaching physics; virtual physics laboratories; computer simulations; physics teacher.

I. Introduction

The development of IT has influenced the educational sector. Today there are a large number of subject-oriented software (mathematics, physics, biology, etc.) designed to facilitate the perception of various concepts, phenomena, and processes. Among such tools, a separate group includes tools to support the teaching of physics, which simplify calculations, record data and build dependencies, simulate various physical processes, etc. A special group is virtual physical laboratories – computer environments that allow you to simulate the behavior of real-world objects in conditions that are close to reality. In such laboratories, the processes of measuring and processing data are undertaken by the computer, and the user's task is only to correctly configure the research parameters and see the existing dependencies.

Teachers in Ukraine, due to the lack of funding for schools with equipment for conventional physical experiments, are looking for alternative ways to teach physic, including the use of digital technologies and means. Methods of their use are not well-established. The degree of their impact on learning outcomes is not unambiguous, so it is advisable to see an existing practice for their use.

The purpose of the study is to characterize the state of implementation of digital technologies and tools in teaching physics, which are presented in scientific publications, and to identify the opinions of physics teachers and students, future physics teachers, on the possibility of using digital technologies in school.

The research methodology provided for analyzing and systematizing scientific publications to identify educational trends in the use of DT in teaching physics, as well as conducting surveys and studying teachers' opinions through conversation. Physics teachers and university students took part in the survey (Sumy region, Ukraine). The total number of respondents is 106 people.

II. Analysis of World Scientific and Methodological Results of the Use of Digital Technologies in Teaching Physics

To identify scientific and methodological results on the use of digital technologies in teaching physics, we analyzed scientific articles contained in the Scopus/Web of Science databases for the last 5 years and devoted them to the use of information technology in teaching physics.

We found trends as follows.

A. The use of digital tools as tools for the study of physical processes

Thus, the work [1] presents the experience of using a high-speed video camera during demonstration experiments in physics. The authors provide examples of experiments used in introductory physics courses that may be relevant in the analysis of the slow reproduction of the filmed material. Article [2] dedicated to using a smartphone as a portable laboratory to perform a variety of physical experiments. In particular, several experiments are described to determine the acceleration of gravity *g*.

B. Using specialized applications to solve physical problems

The resource [3] analyzes the "Physics Master" (https://play.google.com/store/apps/details?id=co.alexis.gbbxs) application, developed by Education Alexis Media, an online coaching institute in India. The application includes a variety of physical quantities dependences and can serve as an assistant in calculating speed, acceleration, and other quantities. Physics Master has the function of a physical calculator, which helps calculate tasks of varying complexity and shows the steps to complete tasks. This mobile application has many topics for studying and generalizing the theory: fundamental quantities, derived quantities, vector, and scalar quantities, measurements, and errors, basics of kinematics, average and instantaneous speed, medium and instantaneous acceleration, uniformly accelerated motion, laws of dynamics, etc. The application also contains online physics courses that will help online solve physical tasks. The application contains recorded video lectures by practicing physicists, typical thematic tasks, online tests, discussion groups, etc. The application "PhysicsMaster – Physics Calc" (https://play.google.com/store/apps/details?id=com.terracciano.physics_master), which is presented in the article [4], allows you to calculate already known values, and organize quizzes that make it possible to study physics in a game form.

C. *Use of virtual and digital physical laboratories*

The article [5] describes the development of various types of virtual laboratories in the field of physics over the past 30 years. The study aims to evaluate the virtual laboratories used in the teaching of physics, in terms of the purpose of use and teaching methods. The authors compare the features of the use of various physical laboratories, the convenience of their interfaces, the tools laid, and the ability to adapt such programs to the target audience. Work [6; 7] is a review and presents the results of content analysis on the choice of virtual physical laboratories in teaching physics by teachers, depending on the topic being studied. Another publication [8] describes the use of online platforms on which, without any equipment, only with the appropriate software and hardware, it is possible to conduct virtual and physical experiments. The authors propose the use of virtual platforms to teach an applied physics course at the Faculty of Natural Sciences and Engineering. Article [9] describes the results of the study of the effectiveness of teaching physics using a virtual laboratory. In the example of the study of geometric optics, the effectiveness of virtual simulations for successful learning outcomes was confirmed. At the same time, there was no significant difference in the attitude of students to the study of physics.

D. *Using virtual and augmented reality to teach physics*

Based on immersive learning technologies, the authors of the article [10] explore the problem of teaching abstract physics topics (in particular, the concept of modern physics). The results of teaching the Gravity Assist concept in a virtual educational environment are presented (Gravity Assist, also known as Gravitational Slingshot or Swing-By, is a method of accelerating or slowing down space probes by exchanging impulses with the planet). This topic requires students to have the skills of abstract multidimensional thinking that has been formed in a virtual environment. Separately, we note that augmented reality can be perceived data generated by application sensors for measuring temperature, distance, acceleration, illumination, noise level, magnetic properties, etc. (Fig. 1).

E. *Use of specialized environments for modeling physical processes*

In the article [11] the method of computer modeling as a teaching method is investigated. The authors prove that this is a full-fledged method of teaching physics. In the article [12], the author demonstrates how you can effectively use the GeoGebra environment (https://www.geogebra.org/) to create animation and modeling in the study of physics. The author presents several examples of digital learning materials: animations, simulations, and computer games that can help to understand terms, phenomena, and processes, as well as improve the assimilation of knowledge and skills in several branches of physics, including motion, dynamics, electrical circuits, and swings. The study highlights the connection between these digital learning materials and the theory of physics.

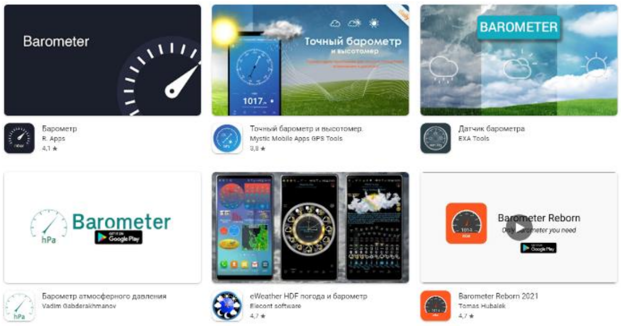

Figure 1. Variety of barometer applications

So, according to the analysis of scientific publications, the following areas of use of digital technologies in teaching physics have been identified:

- the use of digital tools as tools for the study of physical processes;
- the use of applications to solve physical problems;
- the use of virtual and digital physical laboratories;
- the use of virtual and augmented reality in teaching physics;
- the use of specialized environments for modeling physical processes.

III. Analysis of Ukrainian scientific works on the use of digital technologies in teaching physics

The analysis of the Ukrainian scientific space on the methodology of teaching physics at school confirmed the using the above directions of digital technologies in teaching physics. In particular, to prepare for external non-assessment in physics the work [13] offers a mobile application of physical orientation "Physical formulas. Physics" ((https://play.google.com/store/apps/details?id=com.ua.physics) developed by a group of Ukrainian specialists BbytesLab). The application includes basic formulas and tables from the Ukrainian school course of physics (grades 7-11) and can work without access to the Internet.

The authors of the article [14] propose to use Lab4Physics (https://play.google.com/store/apps/details?id=com.lab4u.lab4physics) to conduct an educational physical experiment. Lab4Physics is a program that, along with the measuring sensors embedded in the program, allows you to use the student's phone as a laboratory tool. The authors claim that thanks to this it is possible to conduct a significant number of experiments without special physical equipment. To experiment, you need to select and run the desired virtual tool and point the smartphone at the object whose parameters are measured. The authors note that the advantages of using mobile devices and applications in school lessons include: mobility, accessibility, compactness, and speed.

The paper [15] describes the composition and scope of use of the worldwide digital laboratories Einstein (http://bit.ly/3Xovod9) and Archimedes (http://bit.ly/3wegVEx), which involve the use of various digital sensors, with the help of which a wide range of research, demonstration, and laboratory work in physics can be carried out.

The article [16] describes the creation of a computer laboratory for the use of complex (for example, an oscilloscope) or hazardous devices (for example, a nuclear reactor), which are necessary when studying a physics course. Laboratory robots are programmed (Object Pascal). The author demonstrates an example of modeling a laboratory installation “Study of the phenomenon of electromagnetic induction” and notes that it is important for students to check the models for adequacy – to compare the result and work of the program with experimental data.

The generalization of scientific and methodological results indicates the active use of specialized environments for the visualization of physical experiments and their simulation. Thus, the use of the interactive simulator of physical processes STEP (https://apps.kde.org/uk/step/) is indicated in [17]. The authors describe the method of its use in the study of the elastic pendulum, mathematical pendulum, resonance, mechanical wave, and Brownian motion and confirm its effectiveness by the results of a pedagogical experiment. The article [17] discusses the Proteus environment (https://www.labcenter.com/), which is used to simulate physical processes at the micro level. The authors note that Proteus is a powerful computer-aided design system, which provides the ability to simulate analog and digital devices and simulate their work to detect design and tracing errors. The publication [18] touches on the problem of using Proteus as a means of virtual and augmented reality to visualize the work of individual elements of the information system. The work confirms the expediency of its use in the training of IT specialists.

Separately, we note the popularity of the resource PhET (https://phet.colorado.edu/), which presents online laboratories for teaching physics [19], which visualize many physical experiments, laws, and dependencies. Here are some examples of online laboratories of the PhET resource:

- laboratory work on the topic “Determination of focal length and optical force of a fine lens” (Fig. 2) (https://phet.colorado.edu/sims/html/geometric-optics/latest/geometric-optics_uk.html). Students can study the lenses and the features of their action, analyze the formula of a thin lens, independently establish the relationship between the object and its image under the action of the lens, determine the optical power of the lens;

- laboratory work on the topic “Laws of equilibrium” (https://phet.colorado.edu/sims/html/balancing-act/latest/balancing-act_uk.html). Students can experimentally check what the balance of strength and their shoulders should be so that the lever is in balance.

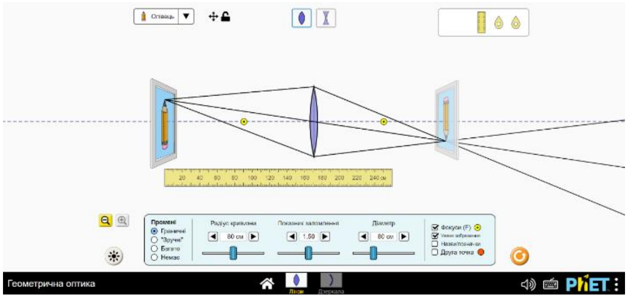

Figure 2. Interactive simulation of the PhET laboratory “Geometric Optics”

The simulation helps students independently compare the relationship of the forces acting on the lever, and the ratio of his shoulders, formulate the equilibrium condition of the lever and analyze what factors affect the accuracy of measurements (Fig. 3);

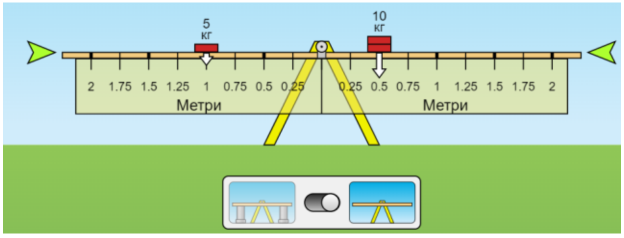

Figure 3. Interactive simulation of the PhET laboratory “Balancing”

- laboratory work on the topic “Boyle–Mariotte, Gay-Lussac and Charles laws for different thermodynamic states of gas” (https://phet.colorado.edu/sims/html/gases-intro/latest/gases-intro_uk.html). Students experimentally investigate isothermal, isobaric, and isochoric processes. Configuring different simulation parameters for each thermodynamic state of the gas in the tank, students observe the change in the concentration of gas molecules and calculate the required physical quantities (Fig. 4).

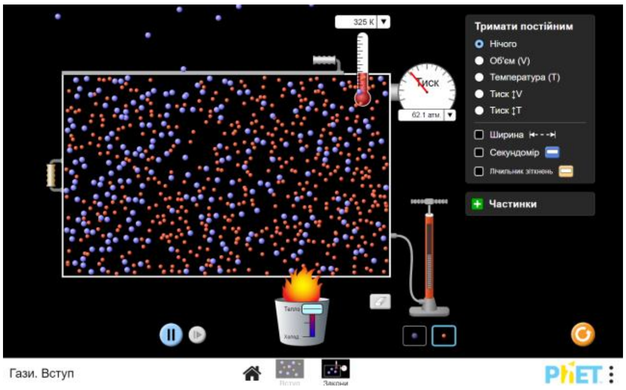

Figure 4. Interactive simulation of the PhET laboratory “Gases”

Thus, the analysis of scientific and methodological publications shows that Ukrainian teachers use digital technology in teaching physics, and according to the content analysis, we note the popularity of using virtual laboratories for the visualization/ simulation of physical processes.

IV. UKRAINIAN PRACTICES OF USING DIGITAL TECHNOLOGIES IN TEACHING PHYSICS - SURVEY

We investigated the issue of using digital technologies in teaching physics in practice. Physics teachers of the Sumy region and students of the Sumy State Pedagogical University named after A.S. Makarenko (specialty "Secondary education. Physics", level of higher education bachelor's and master's) participated in the survey (Table 1).

The total number of respondents is 106 people: 62 physics teachers and 44 students.

Since we recorded five areas of use of digital technologies in teaching physics, and we were interested in the opinion of teachers and students in each of the areas, we offered respondents the following questions:

1) Do you know about the certain direction of using digital technologies in teaching physics?

2) Do you have your own experience in using certain directions of digital technologies in teaching physics?

3) Based on the results of the experience gained, do you want to continue to use digital technology in teaching physics?

4) Do you want to deepen your knowledge and ability to use a certain direction of digital technology in teaching physics?

5) Which of these directions do you consider the most effective in teaching physics (2 positions)?

Questionnaires had the form of a table (according to table 1), where rows are the directions of use of DT, and columns are question numbers. Respondents had to mark the positive or negative answer for every position. The last column required only two positive answers.

The summary results are shown in Table 1.

TABLE I. SURVEY RESULTS

Question	**Question No1**		**Question No2**		**Question No3**		**Question No4**		**Question No5**	
The direction of the use of DT	*Teachers*	*Students*	*Teachers*	*Students*	*Teachers*	*Students*	*Teachers*	*Students*	*Teachers*	*Students*
The use of digital tools as tools for the study of physical processes	37%	43%	13%	25%	13%	25%	82%	100%	85%	95%
The use of applications to solve physical problems	13%	16%	2%	11%	1%	11%	45%	62%	11%	25%
The use of virtual and digital physical laboratories	8%	66%	2%	50%	2%	46%	73%	100%	76%	86%
The use of virtual and augmented reality in teaching physics	5%	14%	0%	2%	0%	2%	31%	68%	29%	25%
The use of specialized environments for modeling physical processes	13%	45%	5%	43%	5%	39%	42%	61%	40%	45%

We will comment on the results.

To question 1 "Do you know about the certain direction of using digital technologies in teaching physics?" we have a situation that, in general, students are more aware of the use of digital technologies in teaching physics than teachers. We explain this by the fact that today every educational program for the training of physics teachers necessarily involves familiarizing themselves with specialized software in the field of physics. Physics teachers in most cases learn about such technologies through advanced training courses or through self-education, which does not guarantee knowledge of all available ways of using digital technologies in teaching physics. During live communication with teachers, it was revealed that it was during the transition to distance learning that teachers' ideas about the range of digital technologies and means of teaching physics expanded.

To question 2 "Do you have your own experience in using a certain direction of digital technologies in teaching physics?" we again have a situation where students give more positive answers than the teachers. We explain this by the fact that students already have experience in learning digital technology in physic, as well as experience in industrial practice, where they introduced such technologies in teaching physics. During personal communication with teachers, it was found that the use of DT based in schools is quite limited: the Internet is not everywhere, access to computer classes is not always available, and not all students and teachers have smartphones where specialized software is installed. Therefore, teachers note a lack of experience. Teachers do not accept applications for solving physical problems as a means of learning (they believe students should solve physical problems independently). Such applications are used mainly for self-testing. Teachers know little about virtual and digital physical laboratories, unlike students who meet them at the university. The use of virtual and augmented reality in teaching physics is new for everyone. Teachers do not use such tools, and students have experience using only complementary realness. Teachers believe that it is not rational to use specialized environments and to model physical processes since it requires a lot of additional time to master the means of learning (it is better to spend this time-solving problems).

Answers to question 3 "Based on the results of the experience gained, do you want to continue to use digital technology in teaching physics?" testify: those who have had experience in using digital technology in teaching physics, will use them in the future. During the conversation, the teachers noted that this was an “interesting experience”, and “the students liked it”. At the same time, we found that there is some bias among teachers about using virtual physical labs to teach physics: there is no access to computers or the Internet at the right time; incomprehensible interface language of apps or computer programs, the inability to install the application on a specific operating system; the inability to install programs on phones, etc.

To question 4 “Do you want to deepen your knowledge and ability to use a certain direction of digital technology in teaching physics?” we recorded significant percentages for students (62% to 100% depending on the direction) and smaller for teachers (from 31% to 82% depending on the direction). It turned out that when teachers are aware of the availability of a certain direction of digital technology and imagine their use in the realities of their professional activities, they have the desire to learn how to use this direction. But after getting acquainted with the peculiarities of conducting a virtual physical experiment in school conditions, they noted that “it cannot completely replace the real one, where it is possible to manually assemble the electrical circuits or arrange in certain way instruments to demonstrate certain physical phenomena.”

To question 5 “Which of these directions do you consider the most effective in teaching physics (2 positions)?” the unanimity of the opinions of teachers and students in favor of the first (the use of digital tools as tools for the study of physical processes) and the third (the use of virtual and digital physical laboratories) directions was recorded.

The first direction was chosen because each physics teacher will surely use available digital tools to confirm or disprove any hypotheses, provided they know how to apply them. The third direction was chosen through high-quality visualization of processes and the ability to organize an independent study of certain topics of physics Teachers note that a virtual experiment allows you to: carry out certain studies, which cannot be reproduced in real life; repeat the study many times, while changing the parameters; save study time on the organization of a real physical experiment; test the model in various, including boundary cases, which in reality can lead to extreme situations.

V. Conclusion

The use of digital technologies in teaching physics is in demand not only because of the need for distance education. It is in demand because of the development of technologies and means, the emergence of immersive learning technologies, and the availability of mobile tools that can accumulate and process empirical data to understand the dependencies of the physical world.

The analysis of theoretical developments proves the spread of experience in introducing digital technologies into physics training, but the practical state of their use in Ukraine testifies to isolated practices. The reasons are not only a weak material and technical base, but also ignorance of the ways to use digital technologies in teaching physics and the unwillingness of working teachers to use such technologies. Therefore, the urgent task of universities is the advanced training of physics teachers who will want to be familiar with various digital technologies and means of teaching physics and are ready to introduce effective methods of their use in their professional activities.

In the future, it is planned to develop a special course designed to form the ideas of physics teachers about the available digital technologies and tools that are already used to teach physics, and develop the skills of their implementation in educational practice.

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